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QUASILINEARIZATION APPROACH TO MHD HEAT TRANSFER TO NON-NEWTONIAN POWER-LAW FLUIDS FLOWING OVER A WEDGE WITH HEAT SOURCE/SINK IN THE PRESENCE OF VISCOUS DISSIPATION

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ABSTRACT

A boundary layer analysis has been presented to study the combined effects of magnetic field, viscous dissipation and heat source/sink on the fluid flow and heat transfer of a power law fluid flowing over a wedge, with magnetic field is investigated. The governing partial differential equations of the hydro magnetic free convective boundary layer flow are reduced to ordinary differential equations by the applications of group theory. By using Quasi-linearization technique first linearized the coupled non-linear equations, and then they are solved by numerically by an implicit finite difference method. Numerical solutions for the governing momentum and energy equations are obtained. Results are presented in terms of the velocity profiles and temperature profiles for the different flow parameters, such as, Magnetic field parameter M, Prandtl number Pr, Eckert number Ec, the flow behavior index n, and the wedge angle parameter m and heat source parameter S. Variation of heat transfer and skin friction for different values of Ec, Pr, M and m are presented. Heat transfer and skin friction results are compared for various values of flow behavior index n governing the nature of the fluid and also for different wedge angles.

KEYWORDS: Non-Newtonian, Flow Behavior Index, MHD, Eckert Number, Heat Source, Finite Difference Scheme

INTRODUCTION

Non-Newtonian fluid is a fluid in which the viscosity changes with applied strain rate. As a result, non-Newtonian fluids may not have well defined viscosity. In modern technology and in industrial application, non-Newtonian fluids play an important role. Many processes in modern technology use non-Newtonian fluids as working fluids in heat exchanger.

The prediction of heat transfer characteristics of these fluids have been studied widely during the past decades. Due to the growing use of these non-Newtonian substances in various manufacturing and processing industries. During the past 50-60 years, there has been a growing recognition of the fact that many substances of industrial significance, especially of multi-phase nature (such as foams, emulsions, dispersions and suspensions, slurries) and polymeric melts and solutions (both natural and manmade) do not conform to the Newtonian postulate of the linear relationship between shear stress and rate of shear in simple shear. Accordingly these fluids are variously known as non-Newtonian, on-linear, complex or rheologically complex fluids. Indeed so widespread is the non-Newtonian fluid behavior in nature and in technology that it would be no exaggeration to say that the Newtonian fluid behavior is an exception rather that the rule. Since 1960, a considerable attention has been devoted to predict the theoretical analysis of an external boundary layer flow for power law non-Newtonian fluids were first performed by Schowalter[1] and Acrivos et al [2].The study of heat and mass transfer in a non – Newtonian power law fluid obeying the Ostwald–de Waele rheological model,

$$\tau_{yx} = -m\left|\frac{\partial u}{\partial y}\right|^{n-1}\frac{\partial u}{\partial y}$$

has been attracting the interest of researchers and scientist in the recent time due to its applications in food, polymer, petro-chemical, geothermal, rubber, paint and biological industries. The two parameter rheological equation (1) is also known as the power law model. When n=1, the equation represents a Newtonian fluid with a dynamic coefficient of viscosity m. Therefore, deviation of n from a unity indicates the degree of deviation from Newtonian behavior. For $n < 1$, the fluid is pseudo plastic and for $n > 1$, the fluid is dilatant .n is power law exponent and m is the consistency coefficient. The flow of a fluid past a wedge is of fundamental importance since this type of flow constitutes a general and wide class of flows in which the free stream velocity is proportional to a power of the length of coordinate measured from the stagnation point. In these types of problems, the well known Falkner-Skan transformation is used to reduce boundary-layer equations into ordinary differential equations for similar flows. It can also be used for non-similar flows for convenience in numerical work because it reduces, even if it does not eliminate dependence on the x-coordinates. The solutions of the Falkner-Skan equations are sometimes referred to as wedge-flow solutions with only two of the wedge flows being common in practice. The dimensionless wedge angle parameter plays an important role in such type of problems because it denotes the shape factor of the velocity profiles. Acrivos et al [2] considered the problem of natural convection heat transfer to power-law fluids for different geometric configuration. The application of boundary layer flow to power law pseudo-plastic fluids, similar solutions has been studied by Schowalter [1].The flow of a power law fluid past a symmetrical wedge is studied by S.S.Elghabaty and Abdel-Rehman [3] in the neighborhood of the stagnation point when an external magnetic field is applied. Kuo Bor-Lih [4] studied the effects of heat transfer analysis for the Falkner-Skan wedge flow by the differential transformation method. W.T.Cheng and H.T.Lin [5] analyzed the non-similarity solution and correlation of transient heat transfer in laminar boundary layer flow over a wedge. The transient thermal response of a power-law type non-Newtonian, laminar boundary flow over a wedge is investigated by Rama Subba Reddy [6]. The flow and heat transfer characteristics of a second-order fluid over a vertical wedge with buoyancy forces have been analyzed by M.Kumari, et al [7].For the non-Newtonian power-law fluids, the hydro magnetic problem of the MHD boundary layer flow over a continuously moving surface over a stretching sheet has been dealt with by several authors e.g. Anderson et al [8], Cortell [9] and Mahmoud [10]. The effect of magnetic field is found to decrease the velocity distribution and thus to increase the skin-friction coefficient. However, relatively less attention has been paid to the accompanying heat transfer problem of power-law fluids past a stretching surface in the presence of a magnetic field. The MHD free-convection flow of non-Newtonian power-law fluid at a stretching surface with a uniform fee-stream was studied by Emad M. Abp-Eldahab and Ahmed M. Salem [11].

The non-Darcy flow characteristics of power-law non-Newtonian fluids past a wedge embedded in a porous medium have been studied by Youn J.Kim [12]. Ramamurthy [13] studied convective heat transfer to power law, non-Newtonian fluids flowing over a wedge with viscous dissipation. MHD laminar boundary layer flow over a wedge with suction or injection had been discussed by N.G.Kafoussias and N.D.Nanousis [14] and M.Kumari [15] discussed the effect of large blowing rates on the steady laminar incompressible electrically conducting fluid over an infinite wedge with a magnetic field applied to the wedge. A non similar boundary layer is presented of mixed convection in power-law type non-Newtonian fluids was studied by Rama subba reddy [16], a boundary layer analysis has been presented by M.A.Mansour et.al[17] Mehmet Akcay[18] studied Flow of power-law fluids over a moving wedge surface.

In the present work, we investigated the effect of MHD heat transfer to non-Newtonian power-law fluids flowing over a wedge with viscous dissipation. The flow is subjected to external magnetic field. The governing flow equations have been solved by Quasi-linearization technique with finite difference scheme.

MATHEMATICAL ANALYSIS

A steady, two dimensional incompressible laminar boundary layer flow of a non-Newtonian fluid, which obeys the power law model, past a wedge of included angle $\pi\beta$ is shown in figure 1. The wedge is maintained at a uniform surface temperature t_w and the free stream fluid has a temperature t_∞. The governing equations of continuity, momentum and energy are:

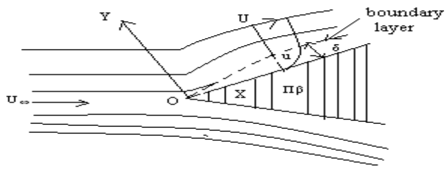

Figure 1

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{dp}{dx}+\frac{n_1}{\rho}\frac{\partial}{\partial y}[(\frac{\partial u}{\partial y})^n]-\frac{\sigma B_0^2}{\rho}u \tag{2}$$

$$u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}=\alpha\frac{\partial^2\theta}{\partial y^2}+\frac{n_1}{\rho c_\rho(t_w-t_\infty)}(\frac{\partial u}{\partial y})^{1+n}+Q(t_\infty-t) \tag{3}$$

Write, the dimensionless temperature $\theta=\dfrac{t-t_\infty}{t_w-t_\infty}$ (4)

And the shear stress $\tau=n_1(\dfrac{\partial u}{\partial y})^n$ (5)

In (5),n_1 is called the consistency index and n the flow behavior index. For shear thickening dilatants fluids n has a value greater than 1 (n>1) and for pseudo-plastic fluids n value less than 1(n<1).

The boundary conditions are

At y = 0, u = v = 0 and θ=1 (6a)

As,y→∞ u = 0 and θ=0 (6b)

The free stream velocity is taken as $U_\infty = Cx^m$ (7a)

Where, the wedge angle parameter $m=\beta/_{2-\beta}$ (7b)

Transformation using group theory

Let $\bar{x}=a_1^{\,l}\,x,\bar{y}=a_1^{\,p}y$ -Independent variables $\bar{u}=a_1^r u,\bar{v}=a_1^s v,U=a_1^w U_\infty$ - Dependent variables

On substitution of the above, the continuity and moment equations will be

$$a_1^{\,l-r}\frac{\partial \bar{u}}{\partial \bar{x}}+a_1^{\,p-s}\frac{\partial \bar{v}}{\partial \bar{y}}=0 \tag{8}$$

$$a_1^{1-2r}\bar{u}\frac{\partial\bar{u}}{\partial\bar{x}}+a_1^{p-s-r}\bar{v}\frac{\partial\bar{u}}{\partial\bar{y}}=\frac{n_1 n}{\rho}a_1^{(p-r)(n-1)+(2p-r)}(\frac{\partial\bar{u}}{\partial\bar{y}})^{n-1}\frac{\partial^2\bar{u}}{\partial\bar{y}^2}+\bar{U}\frac{d\bar{U}}{d\bar{x}}a_1^{(l-2w)}-\frac{\sigma B_1^2}{\rho}a_1^{-r}\bar{u} \quad (9)$$

To establish variance it is necessary to choose the exponents of the parameter 'a_1' in such a way that the transformed equations look exactly the same in terms of the new variables. For achieving this, it is necessary to equate the exponent and cancel out the common powers of a_1.This gives

$$1-r=p-s \qquad \text{From which}$$
$$1-2r=p-s-r=p(1+n)-nr=1-2w$$

$$r=w=\frac{p(1+n)-l}{(n-2)} \quad (10)$$

$$s=\frac{p(2n-1)-l(n-1)}{(n-2)} \quad (11)$$

It is now necessary to find an absolute invariant η_1 which does not vary under the transformation of the independent variable.

Let $\eta_1=yx^b=\bar{y}\,\bar{x}^b\,a_1^{-p-lb}=yx^{\frac{-p}{l}}$ $(\because -p-lb=0)$ (12)

The new dependent variables to replace u and v are now sought and they are to be such that they are invariant under the complete set of transformations. Choosing

$$g_1=ux^d=a_1^{-r-ld}\,\bar{u}\,\bar{x}^d=ux^{\frac{-r}{l}}$$

$$g_2=vx^e=a_1^{-s-le}\,v\,\bar{x}^e=vx^{\frac{-s}{l}}$$

$$g_3=U_\infty x^h=a_1^{-w-lh}\,\bar{U}\,\bar{x}^h=U_\infty x^{\frac{-w}{l}}$$

And considering $g_1,\,g_2,\,and\ g_3$ being functions of η_1, the partial differential equations can be reduced to a set of ordinary differential equations.

Let $g_1=G(\eta_1), g_2=H(\eta_1), g_3=I(\eta_1)$ then

$$u=G(\eta_1)\,x^{\frac{r}{l}} \quad (13)$$

$$v=H(\eta_1)\,x^{\frac{s}{l}} \quad (14)$$

And $U_\infty=I(\eta_1)\,x^{\frac{w}{l}}$ (15)

from (7a) and (15)

$I(\eta_1)=C$ and $\frac{w}{l}=m$ (16)

Substituting (13), (14) along with (12) in continuity equation (1) we get

$$\frac{x^{\frac{r}{l}}}{x}[\frac{r}{l}G-\frac{p}{l}\eta_1 G']+x^{\frac{s-p}{l}}H'=0 \quad (17)$$

Primes denote differentiation with respect to η_1

From (10) and (11)

$$\frac{x^{\frac{r}{l}}}{x} = x^{\frac{s-p}{l}} = x^{\frac{p(1+n)-l(n-1)}{l(n-2)}}$$

Hence, the continuity equation will be $H' = \frac{P}{l}\eta_1 G' - \frac{r}{l}G$ (18)

After substituting the transformed variables in the momentum equation (2) we get

$$x^{(\frac{2r}{l}-1)}[G(\frac{r}{l}-\frac{p}{l}\eta_1 G')] + x^{\frac{s+r-p}{l}}[HG'] = \frac{n_1 n}{\rho}[x^{\frac{r-p}{l}}]^{n-1} x^{\frac{r-2p}{l}}[G']^{n-1}G'' + C^2 x^{(\frac{2w}{l}-1)}\frac{w}{l} - \frac{\sigma B_0^2}{\rho}Gx^{\frac{r}{l}} \tag{19}$$

On substitution of the values for r and s from (10) and (11) the exponents of x terms in equation (19) are found to be equal, that is

$$x^{\frac{2r}{l}-1} = x^{\frac{s+r-p}{l}} = x^{\frac{m-p(1+n)}{l}} = x^{\frac{2w}{l}-1} = x^{\frac{2p(1+n)-\ln}{l(n-2)}} \tag{20}$$

The momentum equation will then be

$$[\frac{r}{l}G^2 - \frac{p}{l}\eta_1 GG'] + HG' = \frac{nn_1}{\rho}[G']^{n-1}G'' + C^2\frac{w}{l} - \frac{\sigma B_0^2}{\rho}Gx^{1+\frac{r}{l}} \tag{21}$$

On perusal of equation (20), it can be seen that

$$\frac{r}{l} = \frac{w}{l} = m = \frac{p(1+n)-l}{l(n-2)} \tag{22}$$

$$\frac{p}{l} = \frac{m(n-2)+1}{(1+n)} \tag{23}$$

And $\frac{s}{l} = \frac{m(2n-1)-n}{(1+n)}$ (24)

Equations (22) and (23) in (18) will change the continuity equation to the form:

$$H' = \frac{m(n-2)+1}{(1+n)}\eta_1 G' - mG \tag{25}$$

Let $G = F'(\eta_1),\quad G' = F''(\eta_1),\quad G'' = F'''(\eta_1)$ (26)

The equation (25) can be written as

$$H' = \frac{m(n-2)+1}{(1+n)}\eta_1 F'' - mF'$$

On integration

$$H = \frac{m(n-2)+1}{(1+n)}\eta_1 F' - F[\frac{m(2n-1)+1}{(1+n)}] \tag{27}$$

Substituting (22), (23), (26) and (27)in (21), the momentum equation will be

$$m(F')^2 - \frac{m(2n-1)+1}{(1+n)} FF'' = \frac{n_1 n}{\rho}(F'')^{n-1}F''' + C^2 m - \frac{\sigma B_0^2}{\rho} F' x^{1+\frac{r}{l}} \tag{28}$$

Hence, it is seen that the continuity and momentum equations combine and reduce to equation (28). Defining new variables $\eta = d_1 \eta_1$ where

$$\eta_1 = \frac{y}{x^{\frac{m(n-2)+1}{(1+n)}}} \tag{29}$$

$$F(\eta_1) = k_1 f(\eta),\ F'(\eta_1) = k_1 d_1 f'(\eta) \tag{30a}$$

$$F''(\eta_1) = k_1 d_1{}^2 f''(\eta),\ F'''(\eta_1) = k_1 d_1{}^3 f'''(\eta) \tag{30b}$$

On substituting (30) in (28), the momentum equation will be as follows :

$$mk_1^2 d_1^2 (f')^2 - \frac{m(2n-1)+1}{(1+n)} k_1^2 d_1^2 ff'' = \frac{n_1 n}{\rho}(k_1 d_1^2)^{n-1} k_1 d_1^3 (f'')^{n-1} f''' + \mathrm{mC}^2 - \frac{\sigma \mathrm{B}_0^2}{\rho} \mathrm{k}_1 d_1 f' x^{1+\frac{r}{l}} \tag{31}$$

Choosing $k_1 d_1 = C$ (32)

$$d_1 = [\frac{\rho}{n_1} C^{2-n}]^{\frac{1}{(1+n)}} \tag{33}$$

And similarity variable

$$\eta = d_1 \frac{y}{x^{\frac{m(n-2)+1}{(1+n)}}},\ M = \frac{\sigma\beta^2}{\rho C} \tag{34}$$

Where $\beta^2 = B_0^2 x^{1+\frac{r}{l}}$ Equation (31) reduces to

$$\frac{d}{d\eta}(f'')^n + \frac{m(2n-1)+1}{(1+n)} ff'' + m[1-(f')^2] - Mf' = 0 \tag{35}$$

The primes denote differentiation with respect to η. From (13), (22), (26), (30) and (7a) the velocity component u can be written as:

$$u = Cx^m f'(\eta) = U_\infty f'(\eta) \tag{36}$$

From (14), (24) and (27), the velocity component v can be written as

$$v = \frac{C}{d_1}[\frac{m(n-2)+1}{(1+n)}\eta f' - \frac{m(2n-1)+1}{(1+n)} f] x^{\frac{m(2n-1)-n}{(1+n)}} \tag{37}$$

Using the values of u and v from (36) and (37), the energy equation (3) can be reduced as

$$\theta'' + A_1.\Pr.f\theta' + (f'')^{1+n}.Ec.\Pr + S\Pr\theta = 0 \tag{38}$$

Where primes denote the differentiation with respect to η and

Modified Prandtl number $\Pr = [\frac{n_1}{\rho C^{2-n} x^{m(2-n)+n}}]^{\frac{2}{(1+n)}} \frac{U_\infty x}{\alpha}$

Eckert number $Ec = \dfrac{U_\infty{}^2}{c_p(t_w - t_\infty)}$

Heatsource/sink $S = \dfrac{Q(t_\infty - t_w)}{U_\infty x}$ and

$$A_1 = \frac{m(2n-1)+1}{(1+n)}$$

The transformed boundary conditions are

At $\eta = 0,\ f = f' = 0, \theta = 1$ (39a)

As $\eta \longrightarrow \infty,\ f' = 1, \theta = 0$ (39b)

Quasi-linearization of all highly non-linear terms Bellman & Kalaba [19] in the equation (35) gives

$$APf''' + A_1Ff'' - (2mF' + M)f' + A_1F''f = A_1FF'' - m(1+(F')^2) \tag{40}$$

Where $AP = n(f'')^{n-1}, A_1 = \dfrac{m(2n-1)+1}{(1+n)}$ and $ap = (f'')^{(1+n)}$ Here F is assumed to be known function, i.e., F is the n[th] approximation to the solution and f is the (n+1)[th] approximation to the solution. Using Crank-Nicolson implicit finite difference scheme, the equations (40) and (38) are transformed to

$$a[i]f[i+1] + b[i]f[i] + c[i]f[i-1] - d[i]f[i-2] = E[i]$$

$$a_1[i]\theta[i+1] + b_1[i]\theta[i] + c_1[i]\theta[i-1] = -E_1[i] \tag{41}$$

$$\begin{aligned}
&a[i] = AP[i] + hA_1F[i] - 0.5h^2(2mF'[i] + M),\\
&b[i] = -3AP[i] + h^3A_1F''[i] - 2A_1hF[i]\\
&c[i] = 3AP[i] + A_1hF[i] + 0.5h^2(2mF'[i] + M),\\
&d[i] = AP[i],\ E[i] = h^3(A_1F[i]F''[i] - m - m((F'[i])^2)
\end{aligned}$$

$$\begin{aligned}
&a_1[i] = 1 + 0.5hA_1\Pr F[i], \quad b_1[i] = (-2) + h^2\Pr S\\
&c_1[i] = 1 - 0.5A_1h\Pr F[i],\ E_1[i] = h^2 Ec\Pr ap[i]
\end{aligned} \tag{42}$$

Here h represents the mesh size taken as h =0.005. The system of equations (41) and (42) has been solved by Gauss-Seidel iteration method and numerical values are carried out after executing the computer program for it. In order to prove convergence of finite-difference scheme, the computations are carried out for different values of h by running same programme. Negligible change is observed, after each cycle of iteration the tolerance set as$10^{-4}$is satisfied at all points.

Heat Transfer and Skin Friction

Heat transfer and skin friction values are very important from engineering point of view. The local heat flux at the surface can be calculated from the Fourier's Law.

$$q_w'' = -K\frac{\partial t}{\partial y}\Big|_{y=0} = h(t_w - t_\infty) \tag{43}$$

Here primes denote the rate of heat transfer per unit area. The local Nusselt number if given by

$$(NU)_x = \frac{hx}{k} \tag{44}$$

In terms of transformed variable

$$(NU)_x = [\frac{\rho C^{2-n} x^{m(2-n)+n}}{n_1}]^{\frac{1}{1+n}} [-\theta']_{\eta=0} \quad (45)$$

or $$\frac{(NU)_x}{(\text{Re})_x^{\frac{1}{1+n}}} = -[\theta']_{\eta=0} \quad (46)$$

Where $(\text{Re})_x = [\frac{\rho C^{2-n} x^{m(2-n)+n}}{n_1}]$

The shear stress at the wall is given by

$$\tau_w = n_1 [(\frac{\partial u}{\partial y}) \Big|_{y=0}]^n \quad (47)$$

And in terms of transformed variables

$$\tau_w = n_1 [\frac{U_\infty^3 \rho}{n_1 x}]^{\frac{n}{1+n}} .(f'')^n \Big|_{\eta=0}$$

This can be expressed as skin friction coefficient by the following equation

$$c_f = \frac{2\tau_w}{\rho U_\infty^2} \text{ or } \frac{c_f (\text{Re})_x^{\frac{1}{1+n}}}{2.0} = [f'']^n \Big|_{\eta=0}$$

RESULTS AND DISCUSSIONS

The system of non-linear equations (35) and (38) are solved numerically under the conditions given by (39), using a marching technique and by applying the Crank-Nicolson implicit finite difference method. The resulting system of difference equations has to be solved in the infinite domain $0 < \eta < \infty$. A finite domain in the η- direction can be used instead with η chosen large enough to ensure that the solutions are not affected by imposing the asymptotic conditions at a finite distance. The independence of the results from the length of the finite domain and the grid density was ensured and successfully checked by various trial and error numerical experiments. Computations are carried out for η_∞=10 which is found adequate for the ranges of the parameters studied here. In order to validate our method, we have compared our results for the Newtonian case (n=1) with those of Ramamurthy et.al [13] and found excellent agreement. Details of the velocities, temperature fields were presented in curves for various values of the different parameters of the problem, e.g., the flow behavior index n, magnetic field parameter M, wedge angel parameter m, Prandtl number Pr, heat source parameter S and Eckert number Ec.

Figure 1(a) – (b) respectively, depict the effect of shear thinning (n<1), Newtonian (n=1), and shear thickening (n>1) fluids on the horizontal velocity profiles f' with η. From the geometrical representation, we notice that increasing the values of the flow behavior index parameter n is to reduce the velocity profile f', which tends to 1 as the space variable η increases from the boundary surface, in the case of (n<1). Further, it is observed that the velocity profiles f' increases with the increase of n in the case of n≥1.

Figure 2(a)-(b) presents the velocity profile f' for (a) m=1.5 and (b) m=0.6 for various values of magnetic parameter M. These figures indicate that an increase in M results in an increase in the velocity profiles f'. However the effect of M is more when m=0.6 in comparison to its effects when m=1.5. The graphs for the velocity profiles $f'$with η for n=1 for different values of wedge angle parameter m are shown graphically in figure-3. The effect of increasing value of

wedge angle parameter m is to increase the velocity profile.Figure.4 illustrate the dimensionless temperature profiles for different values of Prandtl number for Ec = 0.1 and (a) n = 0.8 (b) n=1(c) n=1.6 in the presence of constant wedge angle parameter. The temperature of the fluid decreases with increase of Prandtl number Pr for different values of flow behavior index n. Figures.5(a)-(c) represent the dimensionless temperature profiles for different values of Prandtl number, for Ec=1.0 and various values of wedge angle parameter m. The temperature of the fluid decreases with increase of Prandtl number Pr is observed. Figure 6 (a)-(c) shows the dimensionless temperature profiles for different values of Prandtl number for Ec = 10 and it is seen that the temperature of the fluid increases with the increase in Prandtl number.Figure 7 (a)-(c) portrays the dimensionless temperature profiles for different values of flow behavior index n, when m = 1.0 and Pr = 1.0.for different values of Ec=0.1, Ec=1, Ec=10 is shown respectively. It is noticed that the temperature of the fluid decreases with increase of flow behavior index n. This effect is more when Ec=10. Figure 8 (a)-(c) represent the dimensionless temperature profiles for different values of Eckert number for n=0.8, n=1, n=1.6 respectively. The temperature of the fluid increases with increase of Eckert number Ec noticed. From figure 9 decrease in temperature of the fluid is noticed with the increase of wedge angle parameter m for fixed values of n and Ec.

Figure 10(a)-(c) represent the temperature profiles for different values of heat source/sink S for n=0.8, n=1 and n=1.6 respectively. The effect of heat source/sink parameter S on temperature is executed. From figure it is noticed that the dimensionless temperature θ decreases for increasing strength of heat source and due to increase of heat sink strength the temperature increases. Figure 11 reflects the skin friction profiles $c_f (\mathrm{Re})_x^{1/n+1}$ for different values of wedge angle parameter m. It is observed that the skin friction increases with increase in wedge angle parameter. Figure 12 represents the skin friction profiles $c_f (\mathrm{Re})_x^{1/n+1}$ for different values of magnetic field parameter M. It is noticed that the skin friction increases with increase of M. The variation of heat transfer coefficient $\dfrac{(NU)_x}{(\mathrm{Re})_x^{1/n+1}}$ for different values of wedge angle parameter m is shown in Figure (13). It is observed that the skin friction increases with increase of wedge angle parameter m. The heat transfer is enhanced for the increase of magnetic field parameter M is observed in Figure (14).

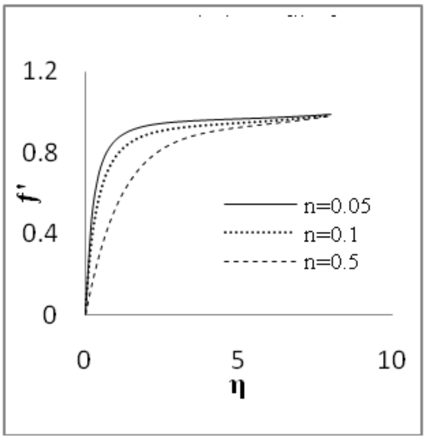

Figure 1(a): Velocity Profiles for Different Values of m=1, Pr=1, Ec=1, M=0, S=0

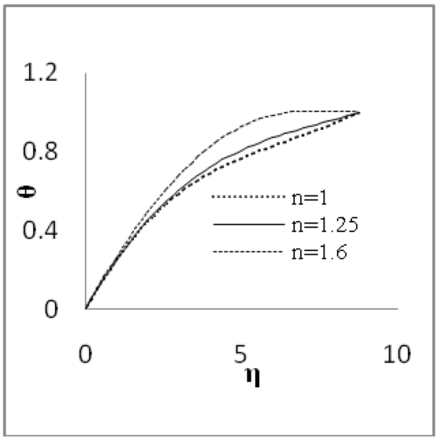

Figure 1(b): Velocity Profiles for Different Values of n, m=1, Pr=1, Ec=1, M=0, S=0

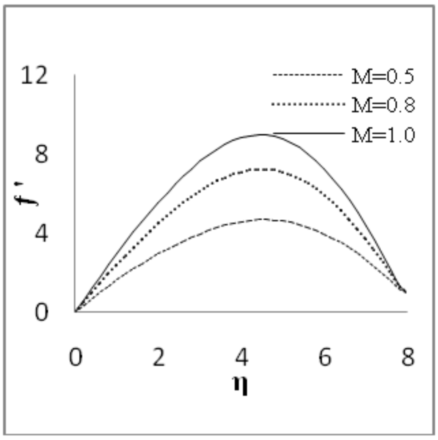

Figure 2(a): Velocity Profiles for Different Values of M n=1, Pr=1, Ec=1, m=1.5, S=0

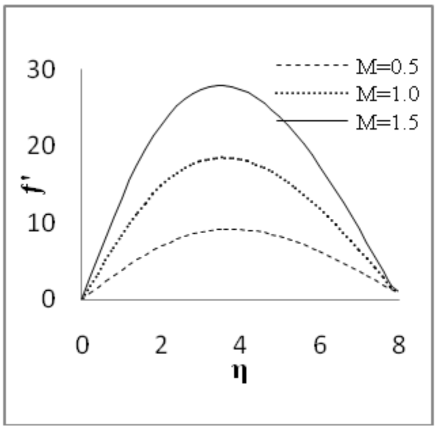

Figure 2(b): Velocity Profiles for Different Values of M n=1, Pr=1, Ec=1, m=0.6, S=0.0

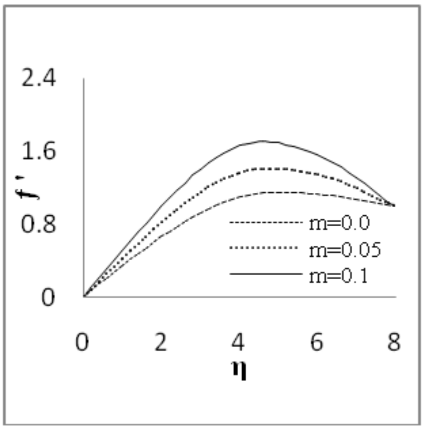

Figure 3(a): Velocity Profiles for Different Values of m for n=1, Pr=1, Ec=1, M=0, S=0.0

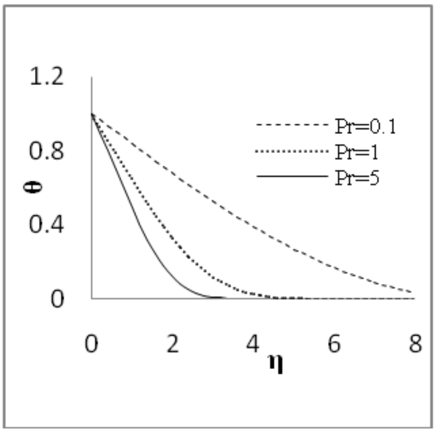

Figure 4(a): Temperature Profiles for Different Values of Pr n=0.8, m=0.1, Ec=0.1, M=0, S=0.0

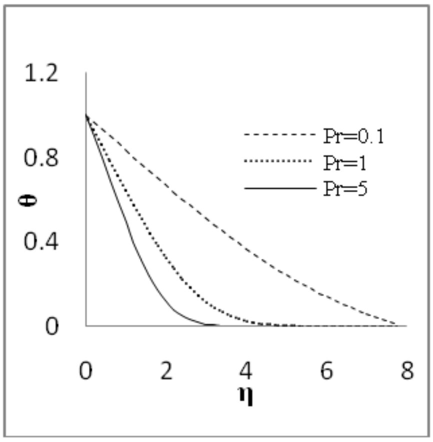

Figure 4(b): Temperature Profiles for Different Values of Pr for n=1, m=0.1, Ec=0.1, M=0, S=0.0

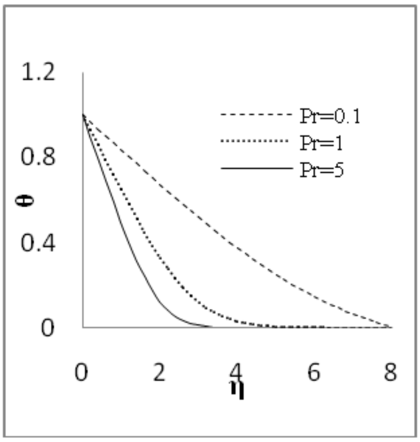

Figure 4(c): Temperature Profiles for Different Values of Pr for n=1.6, m=0.1, Ec=0.1, M=0, S=0.0

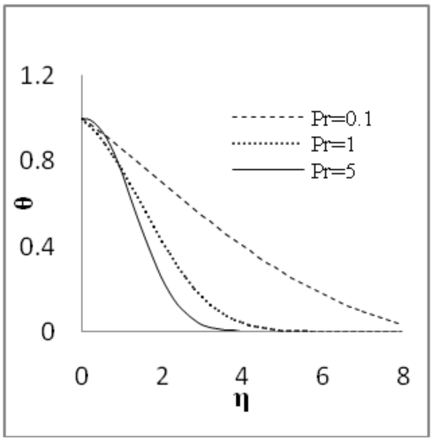

Figure 5(a): Temperature Profiles for Different Values of Pr for n=0.8, m=0.1, Ec=1, M=0, S=0.0

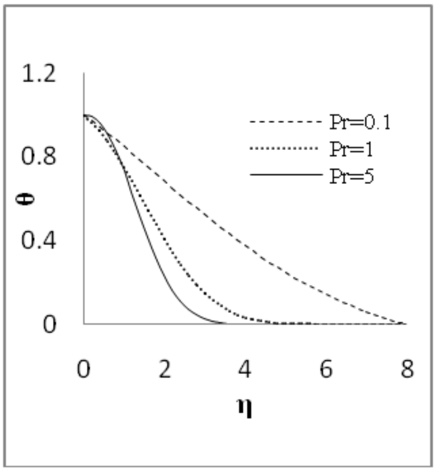

Figure 5(b): Temperature Profiles for Different Values of Pr for n=1, m=0.1, Ec=1, M=0, S=0.0

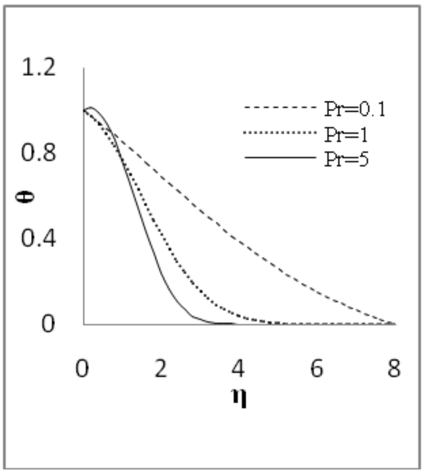

Figure 5(c): Temperature Profiles for Different Values of Pr for n=1.6, m=0.1, Ec=1, M=0, S=0

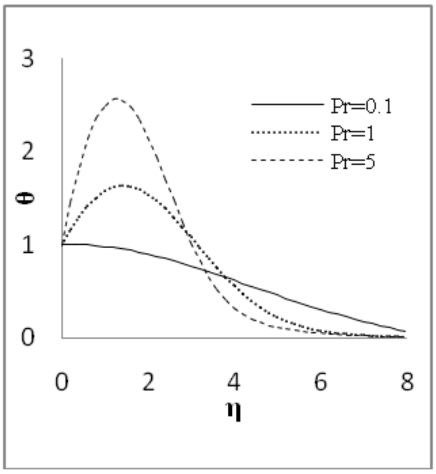

Figure 6(a): Temperature Profiles for Different Values of Pr for n=0.8, m=0.1, Ec=10, M=0, S=0

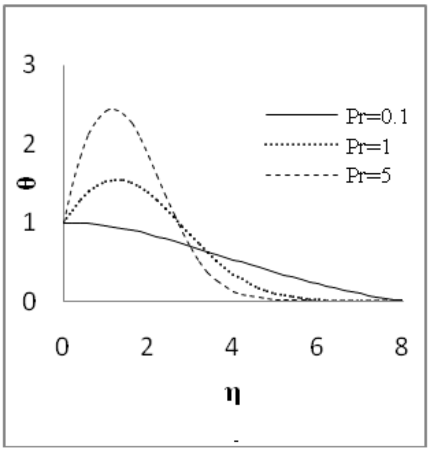

Figure 6(b): Temperature Profiles for Different Values of Pr n=1, m=0.1, Ec=10, M=0.0, S=0.0

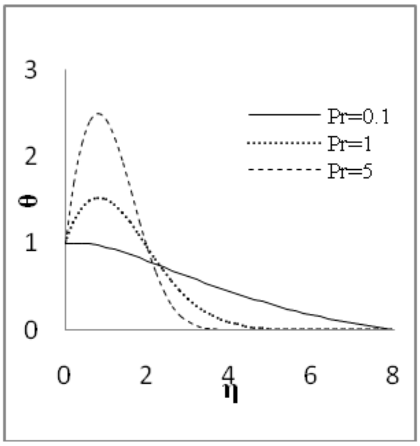

Figure 6(c): Temperature profiles for Different Values of Pr n=1.6, m=0.1, Ec=10, M=0, S=0.0

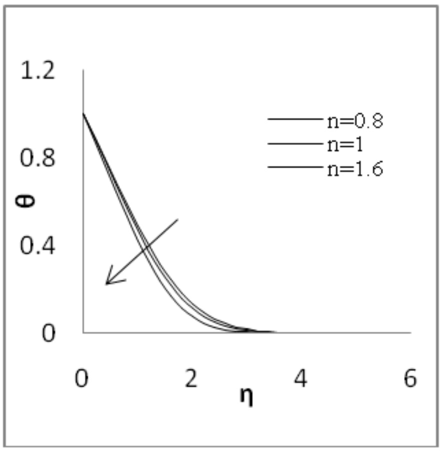

Figure 7(a): Temperature Profiles for Different Values of n m=1, Pr=1, Ec=0.1, M=0, S=0.0

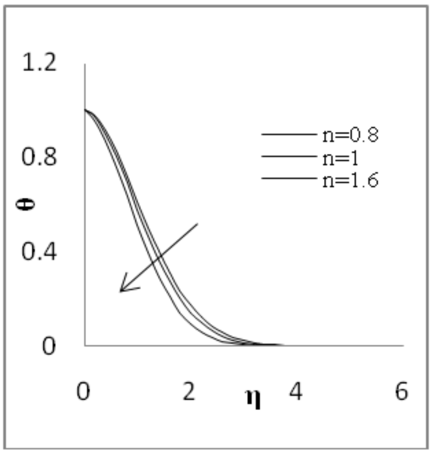

Figure 7(b): Temperature Profiles for Different Values of n for m=1, Pr=1, Ec=1, M=0, S=0.0

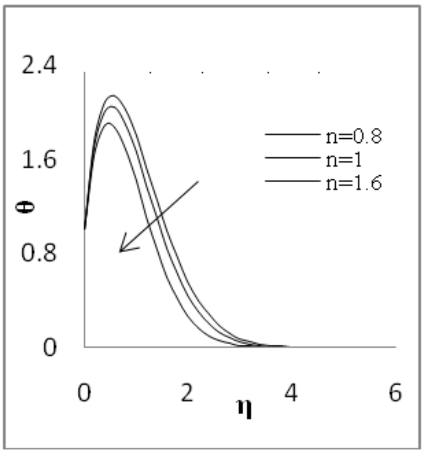

Figure 7(c): Temperature Profiles for Different Values of n for m=1, Pr=1, Ec=10, M=0, S=0.0

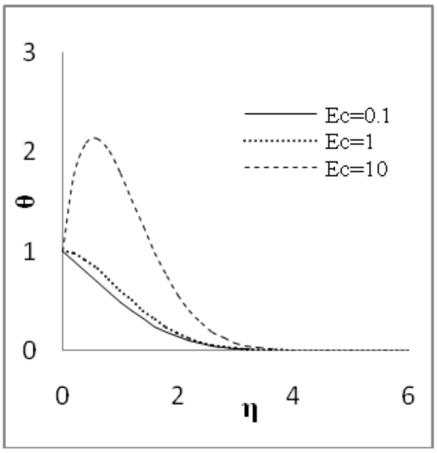

Figure 8(a): Temperature Profiles for Different Values of Ec for n-0.8, m=1, Pr=1, M=0, S=0.0

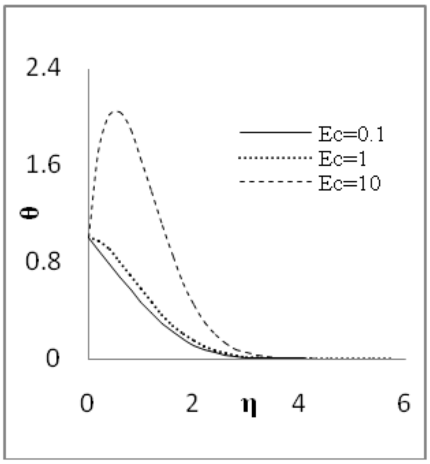

Figure 8(b): Temperature Profiles for Different Values of Ec for n=1, m=1, Pr=1, M=0, S=0.0

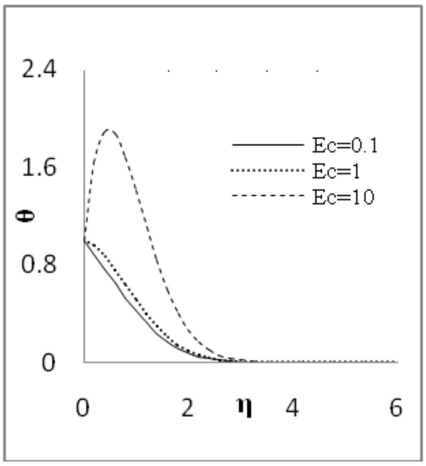

Figure 8(c): Temperature Profiles for Different Values of Ec for n-1.6, m=1, Pr=1, M=0, S=0.0

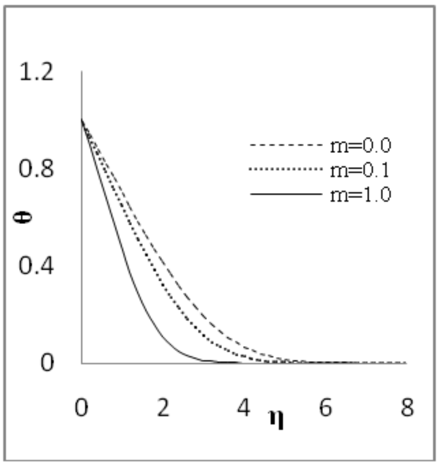

Figure 9: Temperature Profiles for Different Values of m for Ec=0.1, Pr=1, n=1, M=0, S=0.0

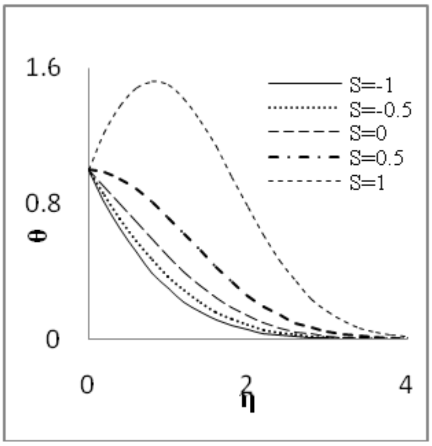

Figure 10(a): Temperature Profiles for Different Values of S n=0.8, Pr=1, m=1, Ec=0.1, M=0.0

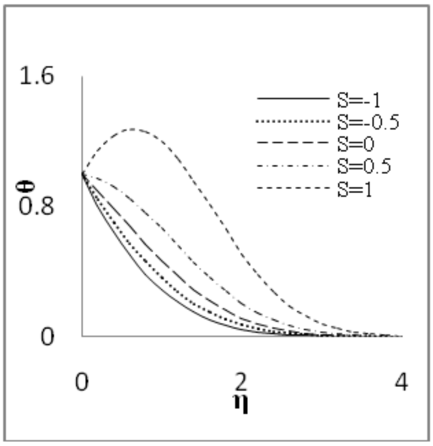

Figure 10(b): Temperature Profiles for Different Values of S n=1, Pr=1, m=1, Ec=0.1, M=0.0

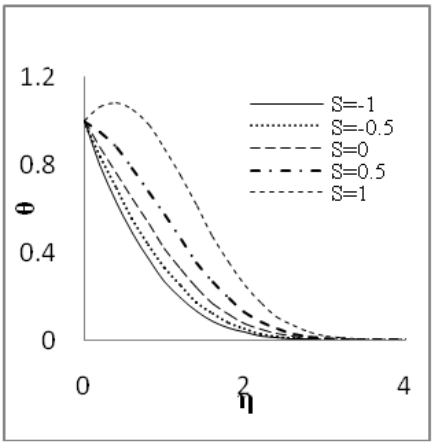

Figure 10(c): Temperature Profiles for Different Values of S n=1.6, Pr=1, m=1, Ec=0.1, M=0.0

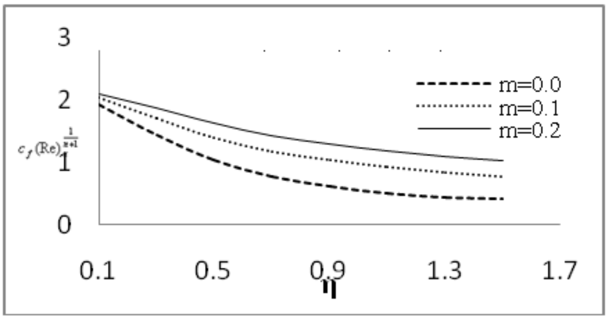

Figure 11: Skin Friction Values for Different Values of m for n=1, Ec=0.1, Pr=1, M=0, S=0.0

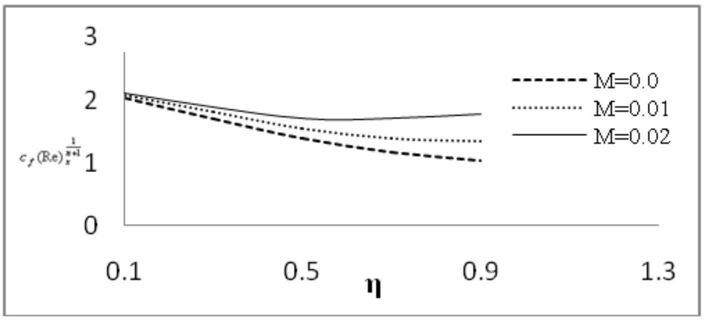

Figure 12: Skin Friction Values for Different Values of M for n=1, Ec=0.1, Pr=1, m=0.1, S=0.0

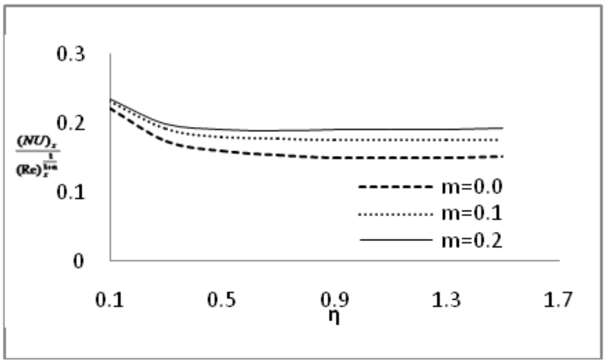

Figure 13: Heat Transfer Coefficient for Different Values of mforn=1, Pr=1, Ec=0.1, M=0.0

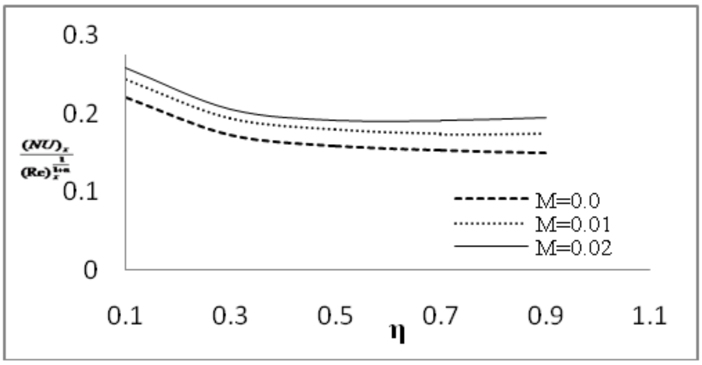

Figure 14: Heat Transfer Coefficient for Different Values of M for Pr=1, Ec=0.1, m=0.0

CONCLUSIONS

The problem of magneto-hydrodynamic flow and heat transfer to non-Newtonian power-law fluid past with heat source/sink in the presence of viscous dissipation is studied theoretically. The governing partial differential equations are transformed into ordinary differential equations by using appropriate similarity transformation and resulting boundary value problem is solved numerically by second order finite difference scheme. The effects of various governing parameters such as the Magnetic field parameter M, Prandtl number Pr, Eckert number Ec, the flow behavior index n, and the wedge angle parameter m and heat source/sink parameter S. Variation of heat transfer and skin friction for different values of Ec, Pr, M and m were examined. The following conclusions are drawn from the computed numerical values.

- The heat transfer coefficient value reduces as the power-law index parameter increases.
- The skin friction value decreases as the power-law index parameter value increases.
- The effect of magnetic field decreases the skin friction values.
- In dilatant fluids the skin friction and heat transfer rapidly decrease as n increases.
- Temperature decreases for increasing strength of heat source and due to increase of heat sink strength the temperature increases.

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